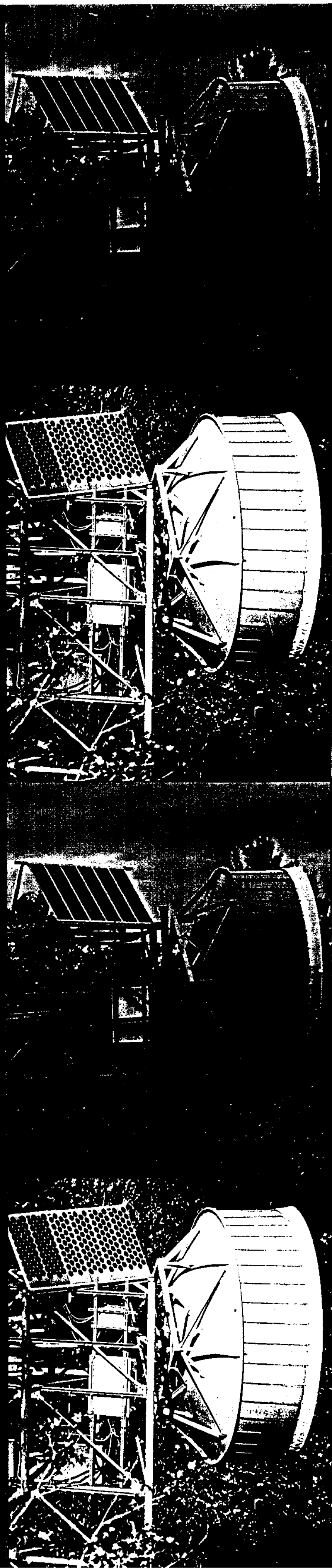

PHOTOVOLTAIC SYSTEMS FOR UTILITIES

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Cover Photo:
The alternating photos show the same Public Service of New Hampshire microwave repeater in 1980 and 1990. The top photo shows the station as fitted with new modules in 1990. Adjacent stations are between fourteen and seventeen miles from this station. The six photovoltaic modules are actually operated as two independent systems of three modules each. Each system feeds a continuous load of 6 watts (0.5-amp feed to redundant amplifiers). The original modules still performed adequately after 10 years, but the front cover material, silicone rubber, had begun to delaminate. Today's modules, (top photo) which are two generations improved from the first installation, have glass front covers and delamination is no longer a problem. The systems use 340-amp-hour batteries and about 140 watts of photovoltaics each. For more information, contact Kenneth Davis at Public Service of New Hampshire, (603) 669-4000, extension 2238.

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PHOTOVOLTAIC SYSTEMS FOR UTILITIES

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ABSTRACT

This report discusses the use of photovoltaic technology within the electric utility industry. Current cost-effective applications – those with immediate payback periods – are illustrated. Readers are given key technical factors that should be considered in determining whether photovoltaics is an appropriate choice to meet their energy needs.

ACKNOWLEDGMENTS

This report is the product of collaborative efforts coordinated by the Photovoltaic Systems Design Assistance Center at Sandia National Laboratories. Special thanks go to the many members of the electric utility industry for assistance in providing pictures and information for the descriptions of the systems.

PREFACE

Many small power applications exist within utility companies and elsewhere for which photovoltaics is the most economic means of providing energy. However, we recognize that photovoltaics is not yet a cost-effective source for bulk power generation today, nor is the photovoltaic industry in a position to supply large power plants to the utility industry.

The aim of the National Photovoltaic Program is to change these conditions through a phased program that allows the photovoltaic industry to grow, taking advantage of the cost reductions that can be gained through increased production while providing utility companies experience with photovoltaic systems, so that they better understand the applications for photovoltaics.

Our purpose in writing this report is to encourage utility companies to consider using photovoltaics for at least some of their small power needs. We have limited this guide to those applications that have immediate payback; that is, those systems for which photovoltaics is a less expensive option than conventional service would be. Even with these limitations, we estimate there are today tens of thousands of applications within utility companies that are appropriate for photovoltaics.

Three recent reports complement this guide: *Photovoltaics for Military Applications* (SAND87-7016), *Photovoltaic Systems for Government Agencies* (SAND88-3149), and *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices* (SAND87-7023). The first two reports illustrate working photovoltaic systems in a variety of locations and for a multitude of uses. They also include practical suggestions on how to procure photovoltaic systems and how to figure out their life-cycle cost. The handbook is written both for the near-novice and the more experienced engineer in the field of photovoltaics, and it includes worksheets for determining the size of a system one needs and examples of working systems. All the publications can be obtained through the Photovoltaic Systems Design Assistance Center at Sandia National Laboratories.

The Center provides contact among potential users of photovoltaic systems, suppliers of systems and components, and qualified engineers who evaluate needs and available equipment. John Stevens (505-846-8068) is the contact for electric-utility-related issues.

CONTENTS

INTRODUCTION

Although photovoltaics is a relatively young technology, many utility companies are already using it for some of their energy needs, and this use has grown from only a few applications in the early 1980s to hundreds today.

	PACIFIC GAS & ELECTRIC	K.C. ELECTRIC ASSOCIATION	PUBLIC SERVICE OF NEW HAMPSHIRE	SOUTHERN CO.	SOUTHERN CALIFORNIA EDISON	FLORIDA POWER CORPORATION	ARIZONA PUBLIC SERVICE	BONNEVILLE POWER ADMINISTRATION
LIGHTING	✔				✔			
SECTIONALIZING SWITCHES				✔			✔	
CATHODIC PROTECTION	✔			✔		✔		
COMMUNICATIONS	✔		✔				✔	✔
WARNING SIGNALS	✔			✔		✔	✔	✔
BATTERY CHARGING	✔							
REMOTE CUSTOMER LOADS		✔						

Some of the uses for photovoltaics are shown in the table above.

Other known utility applications include gas-flow computers, meteorological towers, gas SCADA systems, automated gas meters, automatic gate openers, cloud seeders, and gas samplers.

In this report, we review applications that are cost effective now; that is, those for which a photovoltaic system is less expensive than installing conventional service. They include the applications shown in the table above, but are certainly not limited to them. The following section contains illustrated examples of the experiences electric utility companies have had with photovoltaic technology. Together with the applications, we present factors to consider in making a decision about whether to use photovoltaics. We also show you how to identify, select, and procure a photovoltaic system, as well as provide sources of information and assistance.

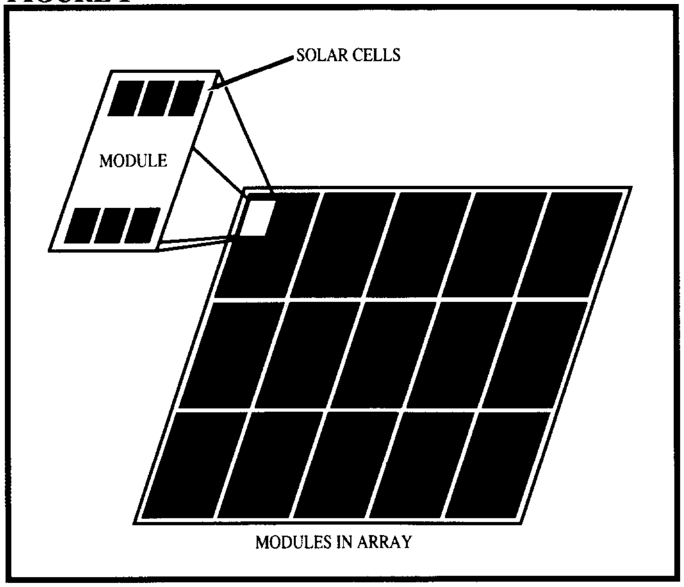
History of Photovoltaics and Current Trends in the Technology

Although the scientific basis of the photovoltaic effect–the direct conversion of light energy into direct current (dc) electricity–has been known for nearly 150 years, the modern photovoltaic cell was not developed until 1954. The practicality of the technology led to its successful deployment in space only four years later. Some of these early systems are still operating in space today and attest to the reliability of the technology. The need for durable, lightweight, and maintenance-free power systems that do not require refueling led to the widespread application of photovoltaic power systems in satellites.

Application of the technology for terrestrial uses was encouraged within federal agencies in the early 1980s. More than 3,100 small systems were installed by nine federal agencies through the Federal Photovoltaic Utilization Program. This program helped to prove the reliability and competitiveness of photovoltaic technology in practical field applications, and many of the systems continue to operate today. The information and experience gained from the program, coupled with government/industry advances in research and development of the technology and improvements in cost of production, have paved the way for widespread acceptance of photovoltaics by many of these agencies.

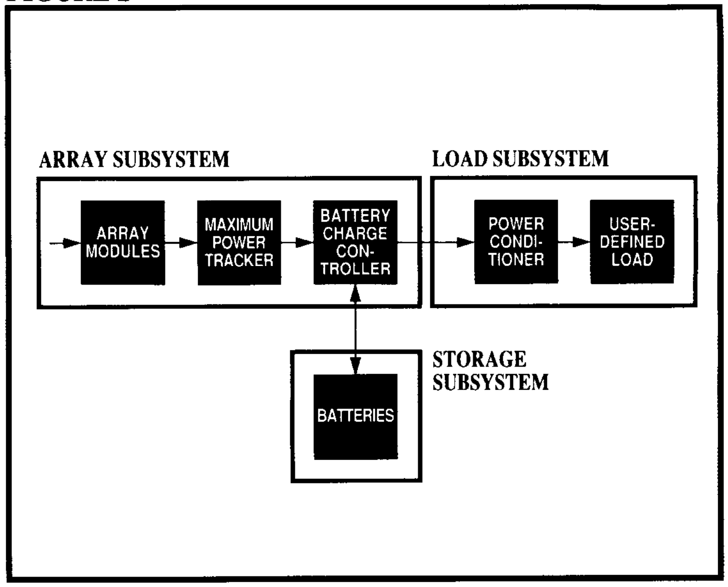
Today, the U.S. Coast Guard uses photovoltaic power as the prime source for all of its aids to navigation; the Department of Defense uses photovoltaics for security lighting, corrosion protection, and other tactical applications; the Federal Aviation Administration, the National Oceanic and Atmospheric Administration, and others use photovoltaics for remote meteorological stations, and the Forest and Park Services use it for campground power. These are only a few of the many applications, and they demonstrate the variety of applications for the technology in public agencies throughout the United States. But an even larger part of the market is in other parts of the world, for uses from rural electrification to powering health clinics.

FIGURE 1



REPRESENTATIVE ARRAY OF PHOTOVOLTAIC MODULES, SOMETIMES CALLED SOLAR COLLECTORS

FIGURE 2



BLOCK DIAGRAM OF A MODULAR PHOTOVOLTAIC SYSTEM

How Photovoltaics Works

Photovoltaics is a descriptive name for a technology in which radiant energy from the sun is converted to direct current (dc) electrical energy. The heart of a photovoltaic system is an array of solid-state devices called solar cells (Figure 1).

Solar cells are made of semi-conducting materials, typically silicon, doped with special additives. When sunlight hits the surface of the cells, a flow of electricity is generated. Desired power, voltage and current can be obtained by connecting individual solar cells in series and in parallel, in much the same fashion as flashlight batteries. Groups of solar cells are packaged into standard modules designed to provide useful output voltages and currents and to protect the electrical circuit from the environment. The modules are connected together to form a unit called an array.

Photovoltaic modules tap solar energy by converting it into electricity to power such loads as lights or electric motors. Because electrical energy is often needed even when the sun does not shine, storage is often required. Batteries are the most common form of energy storage. If the load requires alternating current (ac), an inverter is used to convert the dc power to ac.

Photovoltaic systems are composed of several different components including arrays, inverters, controls, and batteries. By assembling differing sizes of components together, systems can be built with varied power outputs. The modular nature of photovoltaic systems permits them to be expanded easily, ensures minimal maintenance, and allows simple repair or replacement of the system's components (Figure 2).

APPLICATIONS FOR PHOTOVOLTAICS

In general, the photovoltaic power systems described have relatively small loads and, although owned by the utility company and serving utility loads, are not connected to the local utility. The utility's level of involvement varies from those who have determined that photovoltaics is the most reasonable alternative for many small loads, and thus have installed many photovoltaic systems, to those who are just thinking about gaining some experience with photovoltaic systems. In brief, the uses include

- Communications
- Warning Signals
- Sectionalizing Switches
- Cathodic Protection
- Lighting
- Monitoring and Control in Remote Locations
- Battery Charging
- Remote Customer Loads

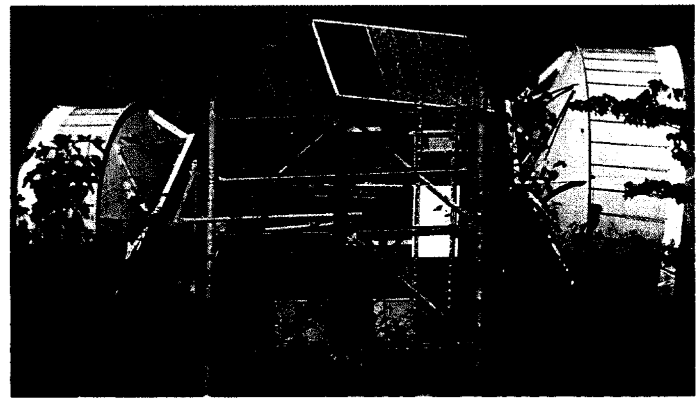
We include the following discussions of how utilities have applied photovoltaics to various uses, and we list a representative from the utility company involved. The applications are throughout the United States.

COMMUNICATIONS

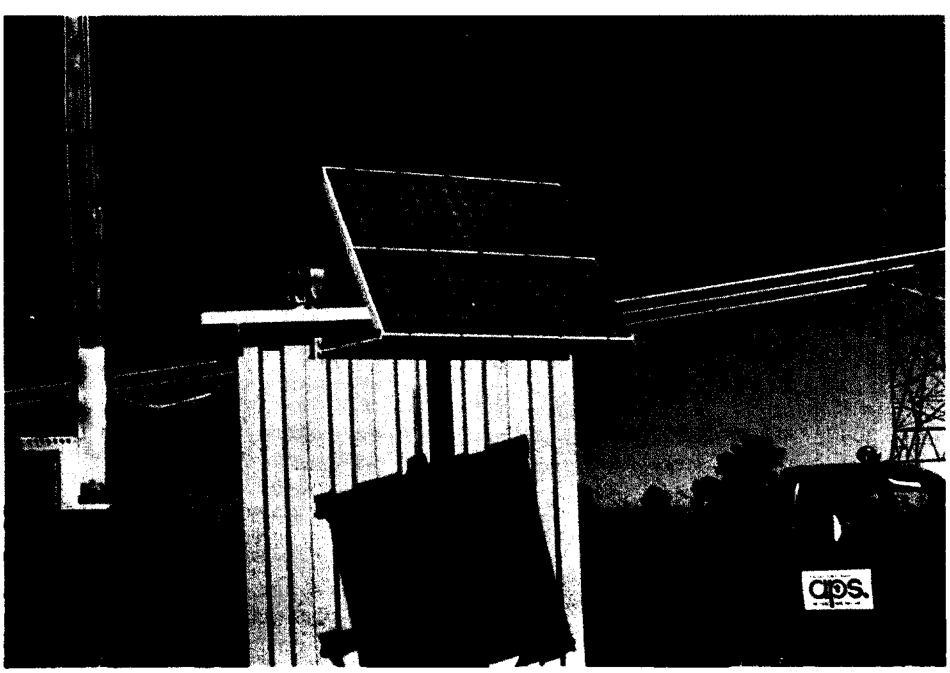
Thousands of photovoltaic-powered communications systems have been installed in the United States and throughout the world, constituting a major application for the technology. Specific applications include

- Microwave repeaters
- Two-way radios and mobile radio systems
- Remote control systems
- Radio communications
- Telephones
- Emergency call boxes

These systems range in size from a few watts of photovoltaic array for call-box systems to several kilowatts for some communications repeater stations. Many of these communications systems are in remote areas with limited accessibility and often with extreme weather conditions, including high winds, heavy snows and ice, and require a high level of reliability.



Public Service of New Hampshire has been operating this microwave repeater with photovoltaic power since 1980. The adjacent stations are in the fourteen- to seventeen-mile range, and the six photovoltaic modules are actually operated as two independent systems of three modules each. Each system feeds a continuous load of 6 watts, (0.5-amp feed to redundant amplifiers). As can be noted from the two photos on the cover, both of the same system, the photovoltaic modules were recently changed. The original modules still performed adequately after 10 years, but the front cover material, silicone rubber, had begun to delaminate. Today's modules, which are two generations improved from the first installation, have glass front covers and delamination is no longer a problem. The systems use 340-amp-hour batteries and about 140 watts of photovoltaics each. For more information, contact Kenneth Davis at Public Service of New Hampshire, (603) 669-4000, extension 2238.



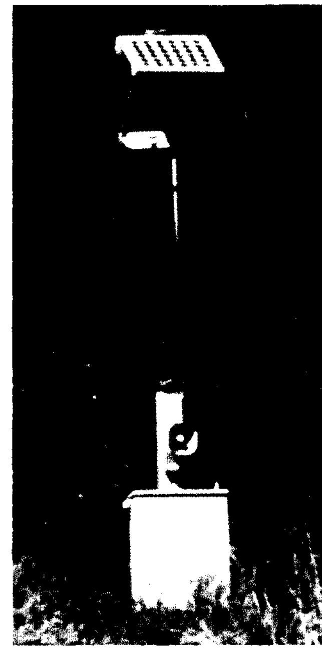
Presently, Arizona Public Service Company has three communication stations that use photovoltaics: Kohinor, Detrital and Lonesome Valley. Kohinor and Detrital are both UHF control link and VHF base station sites. Dispatch communications are relayed from the main microwave sites to both Kohinor and Detrital through the UHF links, and the communications are then dispatched over the VHF radio. Lonesome Valley is a remotely operated line switch. System operators operate this line switch via a communications link powered by photovoltaics. Kohinor and Detrital were originally installed with thermo-electric generators (TEG) which proved to be very unreliable, and necessitated frequent maintenance and propane refueling trips. Replacing the TEG's with photovoltaics, over 10 years ago, was a cost-saving effort. Recently the radios at these stations were upgraded and photovoltaics was chosen to power them again. A capacitive line tap was considered for one of the sites, but the radio system is used most often when the line is out of service, making the load incompatible with the source. Replacement of the photovoltaic system was the most economical since the infrastructure was already in place, and the old panels required little or no maintenance during their lifetime. For more information, call Tom Lepley at Arizona Public Service Co. (602) 250-2826.

WARNING SIGNALS

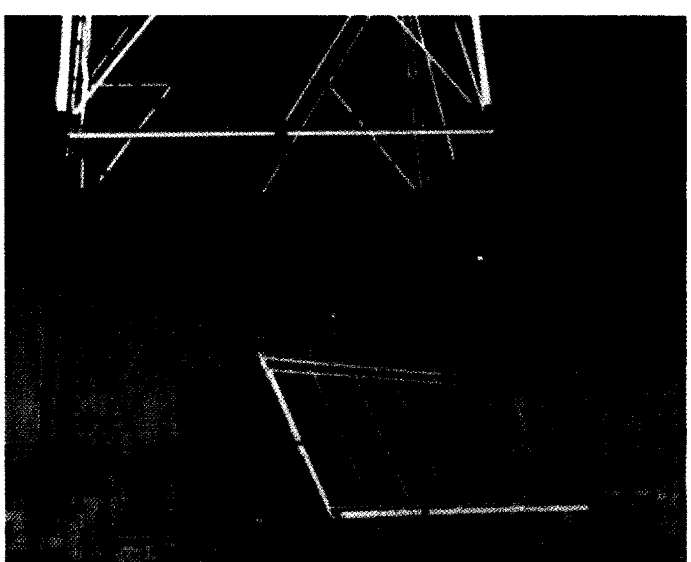
Warning signals are a popular application for photovoltaic systems. Users range from the United States Armed Forces, especially the Coast Guard, to the oil industry, railroads, and highway departments, in addition to the utility industry. Any structure requiring identification or warning signals can be outfitted with a photovoltaic system. Typical systems are on

- Transmission towers
- Navigational beacons
- Power plant stacks
- Audible signals, such as for power plant emergencies
- Highway warning signs
- Railroad signals

Many of these systems are in harsh environments. For maritime use, special modules are made that are resistant to corrosion from salt water. Another concern is protecting the batteries—often they are buried or placed in enclosures with drain holes. The Coast Guard has set its own stringent requirements based on the experience of operating over 11,000 systems in the past few years. In 1984, it began to convert its navigational aids to photovoltaic power and that year saved an estimated $2 million in maintenance costs and about $3 million in the cost of batteries. Contact: Kamil Agi, U.S. Coast Guard, (202) 267-1827.



Of the 131 warning sirens around Pacific Gas and Electric's Diablo Canyon nuclear power plant, five are powered by photovoltaics. These sirens use about 10 watts each of photovoltaics to produce an alert signal for three to five minutes. For more information call Christina Jennings at PG & E, (415) 866-5305.



Bonneville Power Administration has been using warning beacons powered by photovoltaics on transmission towers since the late 1970s. This 1,400-watt photovoltaic system powers a flashing white beacon with two flashing modes: a bright, brief flash during twilight, and a lower intensity flash of longer duration at night. This is one of five such systems; it is on a crossing of the Columbia River.
In 1978, Bonneville calculated that this installation was cost-competitive with a more than 2.5-mile extension of a distribution line and was more reliable than an engine generator. For more information, contact Minje Ghim at Bonneville Power Administration, (503) 230-5049.

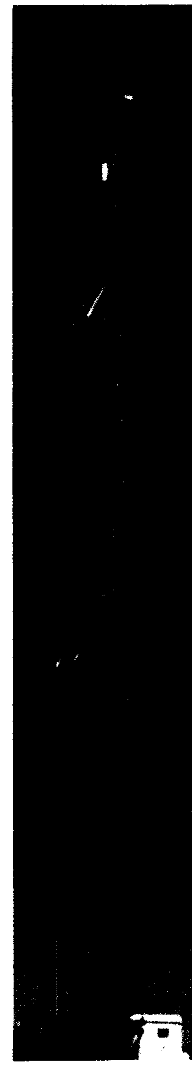
Arizona Public Service Company's Experience With Photovoltaic-Powered Warning Sirens

Arizona Public Service Company operates the Palo Verde Nuclear Generating Station, where 39 sirens surround the 10-mile radius of the plant. Three of the sirens are a significant distance from the nearest distribution line, so photovoltaics was chosen to supply the power for them. The sirens operate from two battery systems: a 24-volt system for the equipment to run the sirens and a 12-volt system that operates a microprocessor-based 20-watt VHF control radio. The upper and lower solar arrays (24 volts and 12 volts, respectively) provide trickle charge current to their respective batteries through a regulator built by the company. The regulator monitors and regulates the outputs of the two panel systems, providing a peak current of approximately 1 amp for the 24-volt system and 2 amps for the 12-volt system.

One array was stolen from a pole and another was vandalized, so the company raised the lowest array to 18 feet above ground. In addition, provisions have been made to monitor the arrays so that an alarm is generated through the control radio to the central controller when panel output is below a minimum specified voltage. Day-to-night transition is accomplished through a set-up that looks for both panels to be active in the daytime or both to be inactive at night. If one array is good and the other bad, an alarm is generated after a delay of approximately 18 minutes, which allows for unequal outputs during sunrise and sunset.

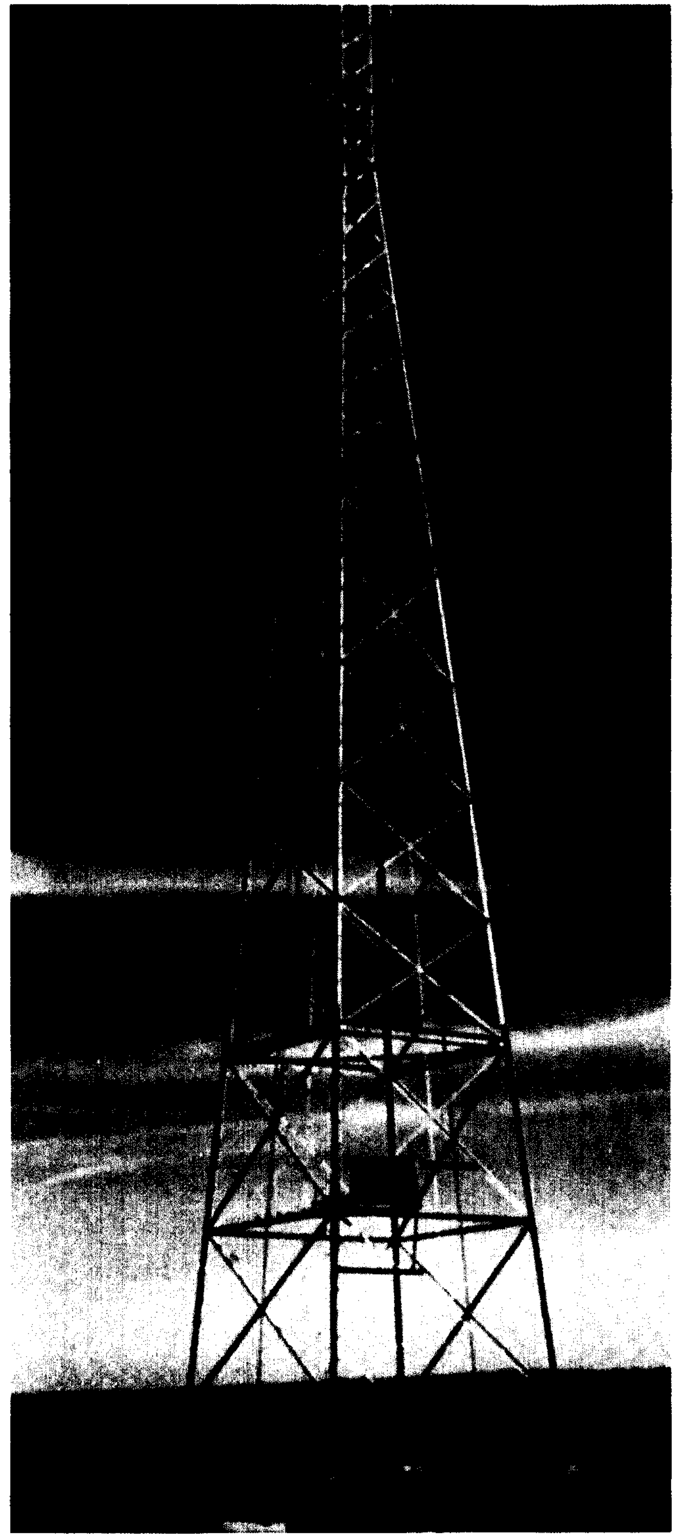
The arrays cost approximately $1,500 each. The siren's total loaded cost would now be about $55,000, as opposed to about $40,000 for the electromechanical units that compose the bulk of the system. The battery life of the 12-volt radio system has been exceptional, with two of the three systems still operating on the original units that were installed in 1982. The operational electrical drain of the 12-volt system is about 8 amps, and the total drain on the 24-volt system is about 40 amps. The life span of the 24-volt system has been about two years, largely because of some high temperatures, but for the most part because the current draw is proportionately much larger than that of the 12-volt system.

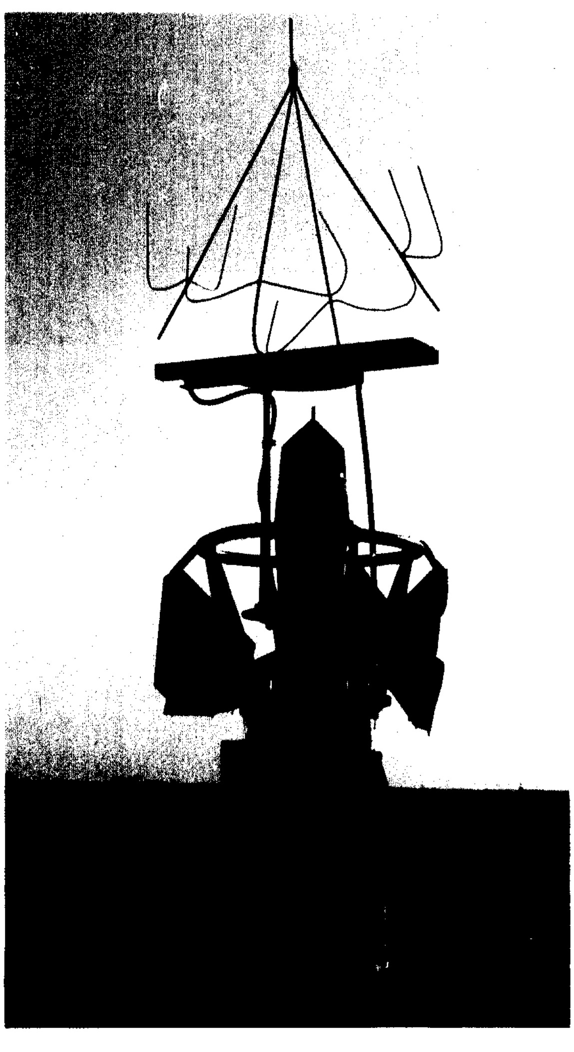
The sirens are tested daily with respect to the radio frequency control link, quarterly as individual units during routine maintenance, and annually as a system to comply with all the Federal Emergency Management Agency regulations. The panels provide maintenance charge on both systems and require about 48 hours to recover totally from operating the siren for three minutes. The batteries are the deep-cycle types, which have very low sag during heavy current draw and will recover well if they are not allowed to discharge below about 1.85 volts per cell. For more information, call Terry Tolley at Arizona Public Service, (602) 393-6115.



An obstruction beacon powered by photovoltaics was installed on a 270-foot 115-kilovolt transmission tower on Hudson Island in Savannah, Georgia for Savannah Electric. The system's voltage is 24 volts (dc) and is designed for an average load of 100 watts. The system consists of a 24-volt (dc) beacon, twelve 12-volt 93-amp-hour batteries, 16 photovoltaic panels rated at 45 watts each, and miscellaneous controls. Panels, batteries, and controls are mounted on top of the tower footing. The photovoltaic array is mounted using standard aluminum array mounts; the batteries and controls are in Fiberglas enclosures. The beacon on top of the tower structure requires no special mounting provisions. The system operates day and night and is designed for five days' autonomous running. The estimated life of the batteries is five years, and the flash tube of the beacon should be replaced every four years. The approximate cost for the total system is $13,000. For further information, contact D. Lane Garrett at Southern Company Services, (205) 870-6352.

In May of 1988 Pacific Gas and Electric installed warning beacons powered by photovoltaics on four 190-foot transmission towers in the south end of San Francisco Bay. Each light is powered by 380 watts of modules. Photovoltaics was used because it was more cost effective than maintaining an existing line that ran through the surrounding mud flats. The company calculates it will save $200,000 over the expected life of the system. For more information, call Christina Jennings at PG&E, (415) 886-5305.





Florida Power Corporation provides power to more than 65 navigational buoys, which are in a wide range of types and have various power needs. The average buoy requires 15 watts. For more information, call Christy Herig at Florida Power Corporation, (813) 866-4338.

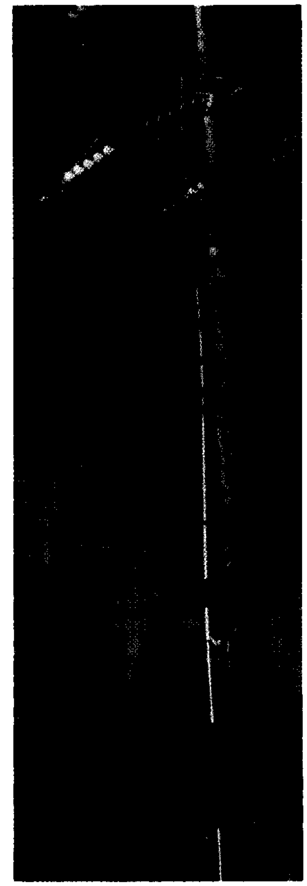
SECTIONALIZING SWITCHES

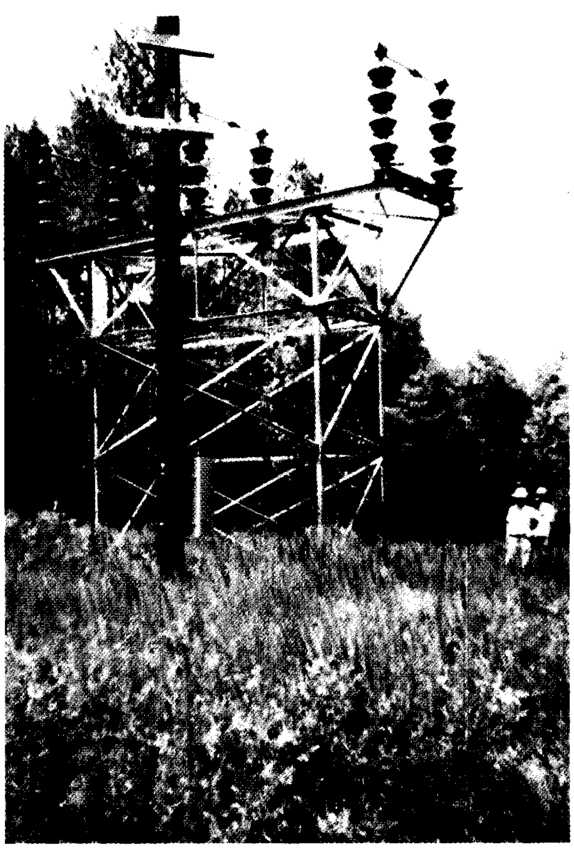
Remotely operated switches, particularly those on transmission lines, are ideal applications for photovoltaic power. These switches typically require a small amount of energy over the course of a year, so a small photovoltaic system can supply them adequately. In addition, they usually have some form of energy storage, because the switch must operate when the line is out of service, and this energy storage will work equally well with photovoltaics as with conventional service. The small photovoltaic system needed for such a load costs a fraction of the price for a transformer capable of interconnecting at transmission voltages. In fact, a photovoltaic system will probably be the least-cost choice even for distribution voltages in those cases for which distribution lines are sectionalized remotely.

Arizona Public Service Company installed seven sectionalizing switches powered by photovoltaics at three locations on its 69-kilovolt subtransmission system. Two of the systems were in the mountains of Arizona where winters are severe. These systems include radio communication links powered by photovoltaics. The switches are powered by compressed nitrogen over oil, and the photovoltaics powers the nitrogen pump.

However, these systems also demonstrate how easy it is for things to go wrong. After being installed, the original radio had problems operating in the very cold climate during the first winter and was replaced with a radio that was more reliable, but also drew more current. The photovoltaic system was not redesigned to account for the added load. The extra current, coupled with the loss of battery capacity at the low temperature, caused the radio's battery to go dead, and the system failed to operate when it was needed. For added reliability, heaters are also needed for the nitrogen/oil system to get the systems through the extremely cold winters. The problem can be solved by using more battery capacity and a larger solar panel. The photovoltaic panels powering the switches have been reliable and have not been a source of problems.

The failure to operate left such a negative impression with the operators of the system that, rather than retrofit the systems, the photovoltaics at two of the locations are being replaced with 69-kilovolt to 120-volt transformers at a cost of approximately $3,000 per transformer per location. One location will remain powered by photovoltaics because it is in a milder climate. For more information, call Jerry Anderson at Arizona Public Service Co., (602) 371-6237.





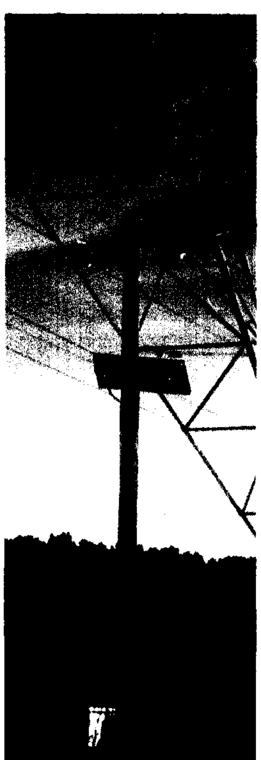
The Georgia Power operating arm of the Southern Company has three sectionalizing switches on its 115-kilovolt system that are powered by photovoltaics. These switches were converted from manual operation to remote as a result of the long time required to reach them, especially in bad weather when they are needed most, and because of the load, television and radio stations, which are important in bad weather. The switches are operated by a 48-volt electric motor powered by batteries, and the batteries are then charged by the photovoltaic system. In addition, there is a 12-volt communication system powered by photovoltaics to allow remote operation.

The motor operator and communications systems each have dedicated batteries and photovoltaic modules because of the different system voltages. The switch uses 40 watts of photovoltaics and 100 amp-hours of battery, and the communication equipment uses 20 watts of photovoltaics and also 100 amp-hours of battery. One of the many good aspects of photovoltaic systems is that there is no cost penalty in providing different power systems at different voltages for loads such as this. The system's cost is about $800 for those components that replace the conventional power source. Contact Lane Garrett at Southern Company Services, (205) 870-6352.

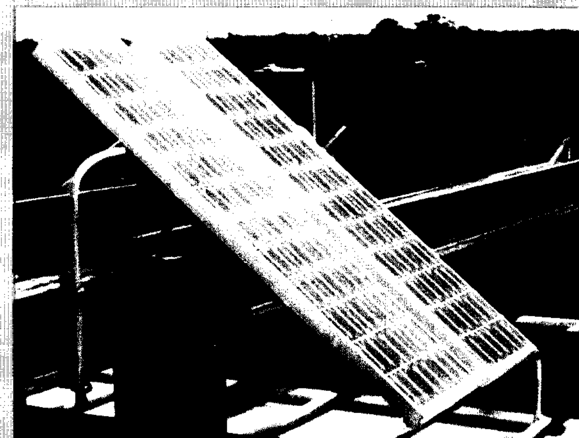
CATHODIC PROTECTION

Each year, metal corrosion causes billions of dollars of damage to structures, pipelines–anything made of metal and in contact with water or ground. Corrosion occurs when metals are exposed to the electrolytes in soils and water. Cathodic protection reverses the flow of electrons–a function photovoltaic systems can readily perform. The systems are quite simple in design, and a wide range of packaged systems exists for this application. Many of the photovoltaic-powered cathodic protection systems operating today require less than 10 kilowatts of power. Typical applications include

- Metal transmission towers
- Pipelines
- Fuel tanks
- Bridges
- Buildings
- Bulkheads including wharves, docks, and marinas.

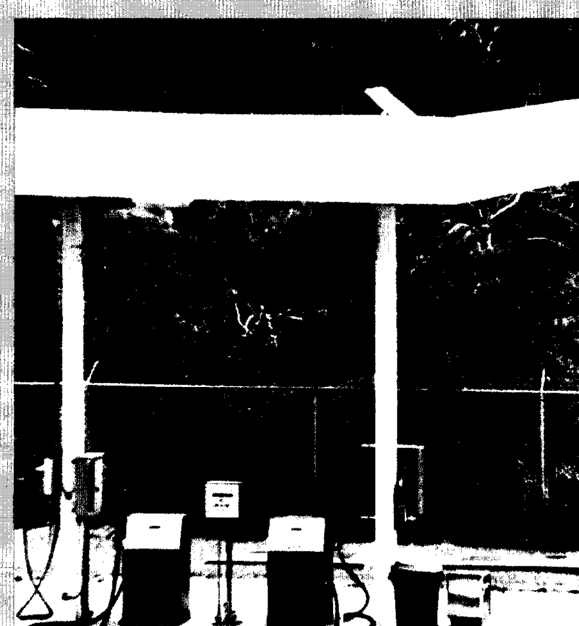


Florida Power Corporation uses photovoltaics to power the cathodic protection system for footings for twelve transmission towers. Each tower requires one 36-watt panel, which operates at about 5 volts. Even if a distribution line were at the site, the cost of a distribution transformer and rectifier would be substantially more than a photovoltaic system costs. For further information, call Christy Herig at Florida Power Corporation, (813) 866-4338.



Southern Company Services has installed cathodic protection systems for underground fuel tanks at two locations within the Gulf Power operating arm of the Southern Company. They were in response to new EPA requirements to reduce the amount of petroleum products seeping into ground water from fuel storage tanks. The regulations now require any buried metallic storage tanks for petroleum products to have cathodic protection. Southern Company Services found photovoltaics could accomplish the task cost effectively, even though the site already had conventional power.

The photovoltaic system costs about $700 per site—the same cost as a rectifier, which would be required if ac service were used. In addition to the rectifier, ac service would also require a secure feed from the local ac distribution panel, as required by regulation. The photovoltaic systems, on the other hand, were quite simple and straightforward. Each system includes about 100 watts of photovoltaics. One system uses a 31-amp-hour battery; the other a 55-amp-hour battery. Both are nominally 24-volt systems. For more information, call Lane Garrett at Southern Company Services, (205) 870-6352.



LIGHTING

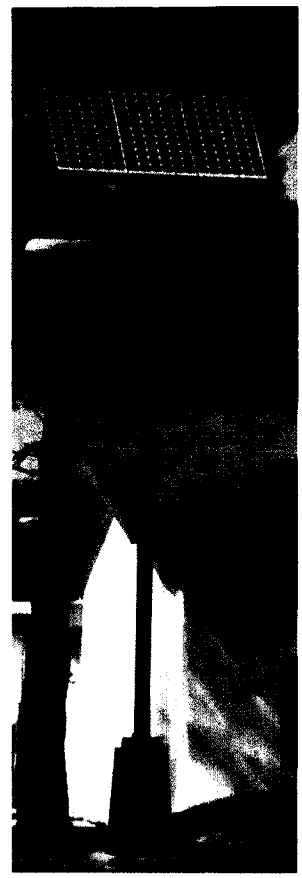
You can find cost-effective lighting systems powered by photovoltaics operating throughout the world–at least 6,000 systems just in the United States. Their principal uses are to illuminate

- Billboards
- Highway signs
- Installations, to provide security
- Public-use facilities, such as parking lots and marinas
- Remote facilities
- Homes and vacation cabins

Recent improvements in the efficiency of lamps and in their reliability, coupled with reductions in the cost of photovoltaic collectors, have significantly improved the economics of these systems. For example, security lighting can be powered by photovoltaics at a fraction of the cost of extending utility lines to remote areas. The lamps can be controlled by timers, photocells, or sensors. Many firms in the United States dealing with photovoltaics sell prepackaged systems containing a photovoltaic power supply, battery, lamp and ballast, and controls. Depending on the requirements, prices vary between a few hundred and a few thousand dollars.

Most photovoltaic lighting systems operate at 12 or 24 volts dc. Although many types of lamps are available, the most efficient type for the lighting needs should be selected. For example, fluorescent lamps are good choices for locations where color rendition is important, and low-pressure sodium is a good choice for security lights, because detecting movement is more important than color rendition. In any case, the selection of high-efficiency lighting, even though it may sometimes cost more than lower efficiency options, will result in substantial savings in the photovoltaic system.

Batteries are required for photovoltaic-powered lighting systems. The batteries and their controller are usually placed in a weather-resistant enclosure, mounted on the pole, behind the light, or buried. The array or module can be mounted on a pole or on the ground, or even on the structure to be illuminated. Elevating the photovoltaic module can reduce the risk of vandalism.



Southern California Edison Company uses more high-pressure sodium lights than any other company in the United States. When the company wanted to use photovoltaics to power this kind of light, no lighting package was on the market that met the need, so the company began to design a system. Pictured is the result of this effort, a prototype 50-watt high-pressure sodium light powered by photovoltaics. It is designed to operate all night during the winter in Southern California. Advanced versions of the system will feature Instant On, in response to motion detectors, programmable controls designed by Southern California Edison; and a second All Night light with low intensity to help a person get close enough to the light to activate the motion detector. This system will be commercially available soon and will be marketed through the company's regulated subsidiary, Energy Services Inc., 7300 Fenwick Lane, Westminster, CA 92683. Questions should be directed to Energy Services' James Clopton, (714) 895-0556.

MONITORING IN REMOTE LOCATIONS

Monitoring at remote sites is one of the largest applications for photovoltaics today, and the total is estimated to be about 20,000 systems. Most applications require less than 200 watts and include monitors for

- Meteorological information
- Water levels, flow rates, and temperatures
- Emission levels of plants
- Pipeline systems

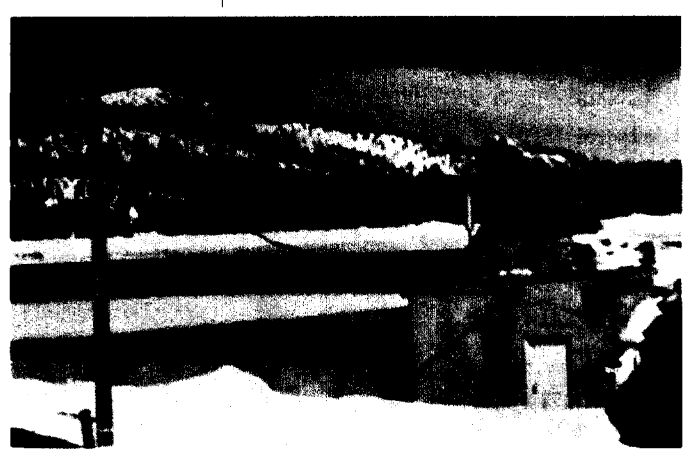
Remote instrumentation and data communications equipment require a power supply to maintain their batteries' state of charge. Photovoltaic power supplies are ideal for this application because of their simplicity and reliability. Almost all of these systems operate at 12 volts dc. The load can vary with the activity, whether continuous or periodic, or the rate at which samples are taken or data are transmitted.

Many monitors require only one module. The data acquisition equipment and batteries are usually located in the same weather-resistant enclosure, which is sometimes buried for protection. Controls for these power systems are usually minimal. The photovoltaic array is usually mounted on the ground or on a pole and should be securely anchored to prevent theft. Experience has shown that pole-mounting at about 20 feet above ground greatly minimizes theft and vandalism.

Pacific Gas and Electric uses photovoltaics to power water level sensors in about 125 locations. When the systems detect high or low water levels, they transmit alarms. This system below Courtright Dam is typical with a 50-watt module. For more information on the system, contact Christina Jennings, PG & E, (415) 866-5305.

CHARGING BATTERIES

Batteries have an inherent problem: they lose capacity over time even if they are not being used. This self-discharge is a problem particularly for organizations that use vehicles only periodically. Photovoltaic chargers exist that can solve this problem: they are modules operating at slightly higher voltage than the battery and producing only a small current. These "trickle chargers" prevent the batteries from discharging, and this application saves many organizations thousands of dollars a year just in avoiding the cost of replacing dead batteries. Applications range from vehicle battery charging, to uninterruptible power supplies, to starting batteries for generators.



Pacific Gas and Electric has a back-up generator at Courtright Dam. A battery bank starts the generator, and PG&E has used 20 watts of photovoltaics since 1988 to keep the starting battery fully charged. For more information, contact Christina Jennings at PG&E, (415) 866-5305.

REMOTE CUSTOMER LOADS

The K.C. Electric Association in eastern Colorado has many installations where miles of distribution line serve only a small load. These loads usually do not generate adequate revenue to cover the cost of installing and maintaining the line. In addition, it is not uncommon for storms,with their high winds, icing, or both to destroy the lines.

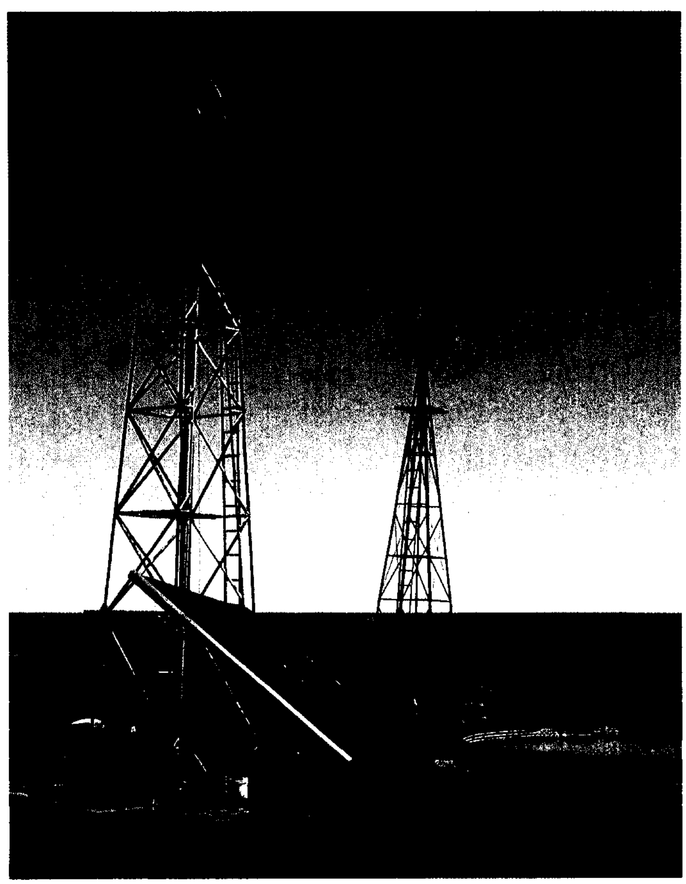
Because many of the isolated loads these lines serve are pumps for watering livestock, KCEA installed a pump powered by photovoltaics so that it could acquire information to evaluate the economics of photovoltaics as a service option. The system also serves as a demonstration to customers of what can be done in lieu of rebuilding a downed line. This system delivers 3,000 gallons per day at a 167-foot head. The entire system, including installation by a private contractor, but not including the well equipment, cost $11,600. In addition, a low-flow, low-head (50 ft, 500 gal/day) system was installed for less than $2,000. For more information about the system, call Jim Zabukover at K.C. Electric Association, (719) 743-2431.

WHEN PHOTOVOLTAICS IS THE RIGHT CHOICE

Should your company consider photovoltaics for a particular application? It comes down to a comparison of alternatives. In most areas of the United States, energy from a photovoltaic system is three to five times the kilowatt-hour cost of conventionally generated electricity (after converting the installed cost into a cost-per-kilowatt hour over the expected life of the system). Yet there are many applications for which photovoltaic power is the most cost-effective option, because the initial installed price is less than the cost of extending conventional service to the load. When thinking of buying a photovoltaic system, the following issues should be considered:

- Access to the site: a well-designed photovoltaic system requires little periodic maintenance. The savings in labor costs and travel expenses can be significant.
- Modularity: a photovoltaic system can be designed for easy expansion. If the power demand increases in future years, the ease and cost of increasing the power supply are minimal.
- Fuel supply: the logistics of supplying fuel to a site with remote generation can be much more expensive than the fuel itself.
- Environment: installation and operation of a photovoltaic system can be achieved with little impact on the environment.
- Maintenance: any energy system requires maintenance. Experience shows that maintaining a photovoltaic system requires less effort than most alternatives.
- Durability: a photovoltaic power supply has no moving parts, and degradation is minimal.

One or more of the above issues ought to be enough to warrant investigating the advantages a photovoltaic power supply can have for your proposed application.



K.C. Electric Association installed a pump powered by photovoltaics so that it could acquire information to evaluate the economics of photovoltaics as a service option.

IT IS EASY TO DESIGN A SYSTEM

Many of the applications presented here exist as packaged systems, with little or no design engineering required. When you buy a photovoltaic-powered light, for example, it can come complete with power system, pole, and mounting hardware. However, if you need, or want, to design a customized system, the process is fairly simple. You should think of the load as being supplied by the stored energy device, usually the battery, and of the photovoltaic system as a battery charger. Initial steps in the process include

- Determining the load (energy, not power)
- Calculating the battery size, if one is needed
- Calculating the number of photovoltaic modules required
- Assessing the need for any back-up energy or flexibility for load growth

Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices details the design of complete photovoltaic systems, something that is beyond the scope of this guide. The accompanying summary shows recommended design practices to give you an idea of what is involved–really not much more than for any other power system. The reference section should be consulted for other sources.

A SIMPLE EXAMPLE

A sketch or back-of-the-envelope estimate of the system's size is often useful for purposes of discussion–either with management about how reasonable a particular application for photovoltaics would be or when talking to a system designer/supplier about the estimated cost for a system. The following example is just that: a back-of-the-envelope technique. It does not account for such design-specific details as the percent the system will be available. For example, a critical communication link might require 99.999% availability, whereas a street light might be fine at 98%. This technique will hit pretty close to the 98% mark.

The sample system is for a street light. The light is 30 watts and will be expected to run all night year-round. Low-wattage, high-efficiency lights are the types that make sense for photovoltaic systems. To see the effect of differing climates, we have designed a system for San Diego and another for Seattle.

FIRST: Design for Worst Case

For this example, the worst case is easy to determine. The load is greatest in the winter, which is the worst case for the load, and the sun shines least at this time, the worst case for the resource. In some instances, the worst case for the load is the summer and worst case for the resource is the winter, requiring you to perform two designs and then to select the one system that will carry the load through both summer and winter. For this example, we assume that the lights are needed for sixteen hours a day in winter. Therefore, the total daily energy requirement is 30 x 16 = 480 watt-hours a day.

SECOND: Throw in a Fudge Factor

At this point, we multiply the load by 1.5 to account for several factors that would be handled individually in a detailed design. Some of the factors accounted for by this method are all the system efficiencies, including wiring and interconnection losses as well as the efficiency of the battery charging and discharging cycles, and allowing extra capacity for the photovoltaic system to recharge the batteries after they have been drained to keep the load going in bad weather. After the multiplication, the load is figured to be 480 x 1.5 = 720 watt hours.

THIRD: Determine the Hours of Available Sunlight

Most solar resource data are given in terms of energy per surface area per day. No matter the original unit used, it can be converted into $kWh/m^2/day$. Because of a few convenient factors, this can be read directly as "sun-hours a day." For example, in the publication *A Comparison of Typical Meteorological Year Solar Radiation Information with the SOLMET Data Base* (Albuquerque: Sandia National Laboratories, SAND87-2379), San Diego is shown to receive 4.6 $kWh/m^2/day$ in December on a fixed surface at latitude tilt (that is, tilted 32.73 ° up from horizontal). This information is available in other publications and is in the often-referenced typical meteorological year (TMY) database. What it means is that the referenced tilted surface will receive the equivalent of an average of 4.6 full sun-hours in December. For the sake of comparison, we also look at Seattle, where the corresponding number is 1.2 sun-hours a day.

As an aside, capturing energy in winter can be enhanced by tilting the surface at a higher angle than latitude. A latitude tilt gives the best energy capture for the entire year, but circumstances may dictate that a different tilt be used. A few figures for San Diego illustrate this point. At latitude tilt, insolation for December, January, and February averages 4.94 sun-hours a day, the summer months average 6.35, and the annual average is 5.79 sun-hours a day. If the tilt is increased 15°, the winter energy increases to 5.29, summer drops to 5.73, and annual drops to 5.68.

Similarly, if the tilt is reduced by 15°, the winter energy drops to 4.31, summer is increased to 6.67, and the annual drops to 5.62.

Two points should be remembered from this discussion about tilt. First, changing the tilt of the array can enhance the energy collection for a certain season. Second, although changing the tilt does affect the annual amount of energy collected, it is not as great a change as one might believe. Note that a 15° tilt change only results in a 3% drop in the annual production of energy.

FOURTH: Determine the Size of the Array

The size of the array is determined by the daily energy requirement divided by the sun-hours per day. For San Diego, the size of the array is 720 divided by 4.6 or 156 watts. For Seattle, the equivalent is 720 divided by 1.2 or 600 watts. This is the size of the array. Of course, it must be modified by the size of the modules available. If 60-watt modules must be used, then you will wind up with 180 watts in San Diego. Remember, when converting calculated array to actual modules, **always round up.**

FIFTH: Determine the Size of the Battery

Most batteries will last substantially longer if they are shallow cycled, that is, discharged only by about 20% of their capacity, rather than being deep-cycled daily. Deep discharge or cycling means that a battery is discharged by as much as 80% of its capacity. A conservative design will save the deep cycling for occasional duty, and the daily discharge should be about 20% of capacity. This implies that the capacity of the battery should be about five times the daily load. To know the daily load, go back to the original load number before the fudge factor–that is, 480 watt hours. Add to this a battery fudge factor of about 50% to account for the efficiency of the battery discharge, the fact that only 80% of the battery's capacity is available, and the loss in efficiency because photovoltaic systems rarely operate at the battery design temperature.

The end result is that the battery design load is 480 times 1.5 or 720, which is coincidentally the same as the array's design load, but for different reasons. This is the daily energy drawn out of the battery, which is now multiplied by five to ensure 20% daily discharge: 720 times five or 3,600 watt hours. This is the battery capacity, which is usually given in ampere-hours so it must be divided by the voltage of the system; 3,600 divided by 12 or 300 ampere hours. Notice that the discussion of the battery's size is independent of the size of the array or the solar resource. In other words, the same battery size works both for San Diego and Seattle because both loads are the same and both arrays are sized to produce the same daily energy.

OPERATIONAL CHARACTERISTICS ARE A MAJOR BENEFIT

Whether a power system must have low environmental impact is specific to each application and location. It is clear, however, that photovoltaic systems exhibit the advantageous features of being silent and non-polluting, and of having no detectable visual or audible emissions. Photovoltaic systems are inherently stand-alone systems; they require no connection to an existing power source nor any supply of fuel. As such, they are less vulnerable to severe weather conditions, poor means of access, and the like. If reduction in the consumption of fossil fuels is a primary concern in selecting a power system, photovoltaics is a good choice.

Photovoltaic systems have advantages over conventional power sources particularly where:

- Reduction in the use of fossil fuels is an important consideration
- A non-polluting source of energy is required
- Security of supply lines for the power source is a concern
- Emissions (audio, visual, etc.) are a concern.

SUMMARY OF RECOMMENDED DESIGN PRACTICES

Many recommendations for producing a stand-alone photovoltaic system that will operate reliably for two to three decades are summarized here. These recommendations come from experienced photovoltaic system designers and installers. The best are based on common sense. Realizing that "the more specific the rule, the greater the number of exceptions," we summarize some of the recommendations here.

- Keep it simple - Complexity lowers reliability and increases the need for technical support.
- Understand system availability - Achieving 99+ percent availability with any energy system is expensive.
- Be thorough but realistic when estimating the load. Many system "failures" have been the result of underestimated loads.
- Check local weather sources - Errors in solar resource estimation can cause disappointing system performance.

- Know what hardware is available and at what cost. Tradeoffs are inevitable. The more you know about hardware, the better you can make decisions. Shop for bargains, talk to dealers, ask questions.
- Know the installation site before designing the system. A site visit is recommended to determine component placement, wire runs, shading, and terrain peculiarities.
- Install the system carefully - Make each connection as if it has to last 30 years–it does. Use the right tools and techniques. The system reliability is no higher than its weakest connection.
- Plan periodic maintenance - Photovoltaic systems have an enviable record for unattended operation, but no system works forever without some care.
- Calculate the life-cycle cost (LCC) to compare photovoltaics to alternatives - LCC reflects the complete cost of owning and operating a system.

PROCURING PHOTOVOLTAIC SYSTEMS

Once the decision has been made to install a photovoltaic system, the question then becomes how to get the project approved and funded. This section provides a discussion of some important points that may help in the approval and funding process.

A case must be made to someone in your organization's management structure that it is in the best interest of the utility to allocate resources to purchase a photovoltaic system. This process differs considerably with individual organizations, the size of purchase, and other factors.

In general terms, the primary justification for any procurement is that it improves the ability to perform a specific mission. Next in importance is a requirement that it do so cost effectively. The justifiable use of photovoltaics in place of traditional technologies for remote electricity generation, such as diesel generators, primary batteries, or grid extension, depends on showing that photovoltaics is more cost-effective, more reliable and/or more secure than its alternative.

Cost effectiveness is usually measured as a combination of factors, such as the system's initial cost, its overall life-cycle cost, convenience, non-polluting qualities, ease of maintenance, and so forth. Although photovoltaics has a relatively high initial cost, its operating expenses are low compared to diesels and other remote power sources, and this makes photovoltaics economically attractive for a wide range of applications. But most important, the cost of an entire photovoltaic power system may be less than having the utility grid extended. Maintenance costs, depreciation, salvage value, cost of capital, and differential inflation rates–all affect the true cost.

Reliability is an important criterion in choosing remote power equipment. With no moving parts, photovoltaic systems rarely fail, even in remote locations and under harsh environmental conditions. Justifications for photovoltaics can be based directly upon reliability criteria, or indirectly upon improved cost-effectiveness resulting from high reliability.

Likewise, the low maintenance requirements for photovoltaic systems can be used to justify procurements. This is particularly true for remote applications where per-trip costs to maintain, refuel, or replace distant generators or primary batteries are significant. Security-related characteristics of photovoltaic technology, such as quiet operation and long-term stand-alone generating capability may also justify procurements of this hardware.

Where to Get Help

The following organizations can provide information and assistance in the areas noted. Vendors are an excellent source of information. A listing of local vendors may be obtained from the Solar Energy Industries Association, as noted below.

- *Solar Energy Industries Association:* As the trade association for manufacturers of photovoltaic equipment, contractors, and professionals in photovoltaics, SEIA can provide up-to-date lists of manufacturers and suppliers of photovoltaic hardware and systems. The association also conducts an annual manufacturers' trade show and exhibit, a good way to find out about currently available photovoltaic products. Contact: Linda Ladas, (202) 408-0660, Solar Energy Industries Association, 777 North Capitol St., Suite 805, Washington, D.C., 20002.
- *Photovoltaic Systems Design Assistance Center, Sandia National Laboratories:* Funded by the Department of Energy, the Design Assistance Center provides information on the design, economics, and applications of photovoltaic systems. With extensive experience with all types of photovoltaic systems, the Center can provide consultation and technical information on virtually any issue related to photovoltaics. Contact: John Stevens (505) 846-8068, Sandia National Laboratories, Division 6223, PO Box 5800, Albuquerque, NM 87185.

- *Electric Power Research Institute:* Electric utilities fund EPRI to perform research related to utility projects. The institute has directors from within the utility industry who help determine the direction of research projects. One area now is photovoltaics, with John Bigger leading an effort to investigate early applications of photovoltaics in the utility industry. Contact: John Bigger, (415) 855-2178, Electric Power Research Institute, 3412 Hillview Ave., Palo Alto, CA 94304.

Steps to Proceed

This document is an introduction to most of the central issues surrounding photovoltaics and its use. Your next step is to take this knowledge and apply it to applications within your company. This is best done systematically using the steps described in previous sections. As a reminder, these steps are summarized below:

- Identify possible applications for photovoltaic systems - Evaluate power needs versus the availability of power at current and planned remote installations to identify candidates for cost-effective photovoltaic applications. Review the applications in this report and identify the instances for which photovoltaics could provide a solution to a problem situation, especially in remote areas.
- Develop preliminary sizing and costing information - Possible applications should be sized and cost estimates made using appropriate methods such as are presented in *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices.*
- Seek technical assistance - You may encounter technical questions that require outside assistance during the implementation process. Firms in the photovoltaic industry will be glad to answer technical questions.
- Prepare justification - Compare the alternatives. Important issues to consider include savings in travel and labor expenses, ease and cost of expansion if power demands increase, logistics of supplying fuel to the site, environmental impact, maintenance requirements, and durability.
- Design and specify system - Bid documents, including drawing specifications and calculations, should be prepared in adequate detail to ensure responsive bidding. Large projects may require the services of an engineering staff or firm to develop a detailed set of working drawings and specifications. An important part of this effort is to determine the scope of outside contracting that is needed. In other words, is the system to be installed by in-house personnel or will the installation also be performed by the contractor?
- Select contractor - Usually the size of the procurement dictates the rules for selecting the contractor. In addition to offering a competitive price, the winning contractor should have a successful record of implementing photovoltaic systems and an acceptable warranty period.
- Install system - Your photovoltaic system should be installed in a professional manner to ensure that it has high performance, reliability, and longevity. Packaged systems are available for a number of photovoltaic applications, and their use speeds and simplifies installation.
- Operate and maintain system - Once the photovoltaic system has been installed and accepted, provisions must be made to operate and maintain it. The photovoltaic array itself has minimal maintenance requirements, but the batteries, power conditioners and connected loads each typically require a modest amount of attention from the user. Periodic preventative maintenance is the best strategy for minimizing future problems. In contrast to competing diesel generation and primary battery technologies, photovoltaic systems typically enjoy low operation and maintenance expenditures.

Photovoltaic technology is useful and cost-effective for a wide variety of small, remote applications. It is likely that photovoltaics is the technology of choice for a number of applications within your company. Take this opportunity to identify and implement feasible and attractive projects using photovoltaic technology.

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